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DEMONSTRATION OF A SMALL BIOMASS POWER PLANT

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ABSTRACT

The U.S. Environmental Protection Agency's (EPA's) Air and Energy Engineering Research Laboratory (AEERL) is cooperating with the Research Triangle Institute (RTI) to demonstrate that converting wood energy to electrical power results in waste utilization, pollution alleviation, and energy conservation.

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INTRODUCTION

Utilizing biomass as a fuel for power generation will eliminate sulfur dioxide (SO_2) emissions, produce zero net gain of carbon dioxide (CO_2), reduce air toxic emissions, and help solve waste disposal problems. Additional benefits from fueling a power generation system with biomass are savings from avoiding landfill tipping fees for disposal of biomass residues, savings from decreasing or eliminating the purchase of fossil fuels and/or electricity, and energy security from using indigenous biomass for fuel. EPA biomass energy projects are intended to provide the impetus needed for the development of equipment, design of systems, creation of markets, and promotion of exportable technologies.

This project has the objective to demonstrate that an innovative energy conversion technology fueled with biomass is technically, economically, and environmentally feasible for Camp Lejeune and other Department of Defense (DoD) installations, industrial sites, and developed and developing countries. The approach has been to identify a site, the partners, and the most viable technology, then design, build, and test the technology. The coordination between DoD and the partners will be such that the design of the project will be in the best interest of Camp Lejeune. The technical risks will be minimized by the proper selection of technology based on the available site, size of system, type of fuel, qualifications of operators, and lessons learned by all cooperators.

Converting wood to power at military installations will result in waste utilization, alleviation of pollution, and energy conservation. This is a real contribution toward meeting Federal directives to stabilize CO_2 emissions at 1990 levels by the year 2000, and to reduce Federal agencies' energy consumption to 20% below 1991 levels by the year 2000 (Executive Order 12759). The project also has excellent potential for technology transfer to the commercial sector and other public agencies which follows a trend of revived commercial interest in wood energy and growth of independent power production and industry-site power plants.

CAMP LEJEUNE DEMONSTRATION

The 3-year, Camp Lejeune demonstration project is intended to demonstrate a biomass-to-energy conversion technology at a scale of approximately 1 MW of electrical output, on the Marine Corps' Base in North Carolina. Camp Lejeune is located in the Coastal Plain of North Carolina and occupies approximately 153,000 acres (6.2×10^8 m^2). The Base has 45,000 active duty personnel, 4,500 civilian employees and about 12,000 dependents. The Base utility is about 30 to 40 MW, with peak summer demand reaching a maximum 70 MW. Five initial sites on the Base are under consideration for the demonstration, with all but one having an electrical substation in close proximity.

The biomass fuel for the demonstration will be generated by activities on the Base, in the community, and/or from dedicated feedstock supply systems. Table 1 shows Camp Lejeune's waste products generated on the Base each year. Over 22,000 tons per year (tpy) (19,958 metric tpy) of combined wood products and tree limbs are available. Most of the waste is currently being landfilled, and a waste recovery program is sought that will be of benefit to the Base. The waste will become the fuel for the demonstration and will be delivered in chipped or hogged fuel-size to the demonstration site by Base operations. It is estimated that up to 90% of this waste will be used for the demonstration plant. Fuel

preparation will include metal and other trash removal, and grinder operating conditions for optimum fuel size. Fuel handling and fuel hoppers are dependent on average fuel size and the bulk storage configuration. A 1 MW operation can deplete the volume equivalent of a typical business office every 3 to 5 hours; i.e., a 3 hour hopper might have a 1000 ft^3 (28.32 m^3) volume. Table 2 estimates tons per hour (tph) of partially dried wood fuel required for a biomass energy conversion system operating over a range of sizes and efficiencies. Also available, if necessary, are the logging residues from the Base's annual timber harvest. About 300 acres of timber are harvested at Camp Lejeune annually. Most of the timber harvested is loblolly pine, with some longleaf pine and hardwood (a mixture of oak, sweet gum, and poplar). An estimate of the amount of associated waste wood and rough trees is 1000 tpy.

TABLE 1. Available waste biomass as indicated by the proposed waste reduction plan prepared by Camp Lejeune Environmental Management Department (Based on tonnage reports from March 1992 through February 1993)

Material	Total TPY	Recycle			Compost			Lined Landfill		
		Tons	%	FY	Tons	%	FY	Tons	%	FY
Wood Products	7,067	6,667	8.37	94				400	0.50	96
Tree Limbs	15,187	15,187	19.07	94						
Yard Wastes	1,663				1,663	2.09	93			

TABLE 2. Required tons per hour of dry wood at 6000 Btu/lb (13,956 kJ/kg)

Power (MW)	System Efficiency for Electrical Production			
	10%	15%	20%	25%
0.5	1.42	0.95	0.71	0.57
1.0	2.84	1.90	1.42	1.14
2.5	7.11	4.74	3.56	2.84
5.0	14.20	9.48	7.11	5.69

The maximum space required for a 1 MW unit (e.g., two modules of 500 kW each) may cover about 30 X 40 ft, with elevations of 18 to 25 ft. The required fuel storage area is estimated at 60 X 180 ft for 3 days storage or 100 X 300 ft for 1 week storage, with piles covering 16 X 60 ft and 6 ft in height. A structure approximately 30 X 40 ft is also planned for fuel drying.

The demonstration project plan emphasizes selection of an energy conversion technology which is mature in its

development (consisting of a substantial portion of off-the-shelf equipment) but also innovative. It is planned that the biomass conversion plant will represent a commercial option for electrical generation which will be transportable, modular, and relatively low-cost. This provides an option for waste wood utilization at industrial and small municipal sites, as well as many applications in developing nations. Four major equipment units dominate the plant installation: 1) fuel hopper and feed system, 2) furnace/gasifier and ash hopper (including air fan), 3) gas cleanup, and 4) engine/generator set.

The technology selection phase is in progress. Five factors for evaluation are emphasized in the first stage of the selection phase. These factors are being considered for hypothetical plants at 1 MW and assume that the technology has progressed beyond prototype to a standard, commercial design. Therefore, factors include costs and risk to bring the technology to this state of maturity. The factors are:

1) Relative technology risk -- this includes the maturity of the technology, evidence from previous prototype demonstrations, requirements for modules that have received only limited evaluation or research, and known engineering limitations.
2) Innovation -- usually accompanied by high relative risk, innovation includes less mature technology with high <u>potential</u> for performance, cost, and environmental improvements.
3) Efficiency -- a measure of anticipated overall energy conversion performance, or heat rate. Evaluated on per-module and overall plant bases.
4) Cost -- includes both operating and investment costs relative to other processes compared for a base year and standard amortization.
5) Simplicity -- addresses estimated ease of installation and operation. Modularity and transportability will allow for varying fuel supplies and/or energy demand.

There are also five categories of wood-energy-to-electricity conversion options: 1) the conventional combustion boiler and steam turbine/generator (T/G) (condensing), 2) combustion with expansion of gas products through a recuperating-type turbine (air turbine); and three options for utilizing low/medium Btu gas from a wood gasifier -- 3) gas turbine, 4) gas combustion in a boiler with a steam T/G set (condensing), and 5) reciprocating spark ignition or diesel engines.

Regarding fuel conversion options, the hot flue gas or hot air turbines are relatively low risk. Hot combustion products may be generated in a turbocharged pressurized furnace; or clean, hot, pressurized air may be produced by heat exchange with a biomass furnace and the air used to drive an expansion

turbine.

Low to medium Btu gas from biomass gasification still presents some major difficulties for small, high-speed combustion turbines. However, there are reciprocating engines which operate well with wood gas, like the internal combustion engines operated off simple gasifiers during World War II. Both diesel and spark ignition operation are possible with wood gas. Diesel operation requires augmentation of the wood gas with 5 to 10% of diesel fuel by energy content to reach pressure ignition conditions. Efficiency is considerably improved for both types of engines by turbocharging. The problem is that the close tolerances of turbochargers are susceptible to fouling by gasifier tars. Experimental results have produced estimates that tar must be reduced to no higher than 10 to 20 ppm (parts per million).

A preliminary technology comparison is presented in Figure 1 using a rating scale of 1 to 5 (5=best), where each category must receive its own (not a duplicate) ranking. When all factors are averaged, the combustion air turbine ranks best (at this scale of operation) because it is innovative but relatively low risk and can incur only moderate costs. This category is followed by gasifier/engine, combustion/steam turbine, gasifier/gas turbine, and finally, gasifier/steam turbine. Obviously, arguments can be made about the relative factors but, within project goals, the first evaluation is considered qualitatively accurate. Steam turbine cycles have been essentially eliminated because they are too conventional and require a water/steam cycle. Other options are still under consideration. Influences, such as a breakthrough in gas cleanup technology that promotes gas turbine reliability, could have a significant effect on the final evaluation.

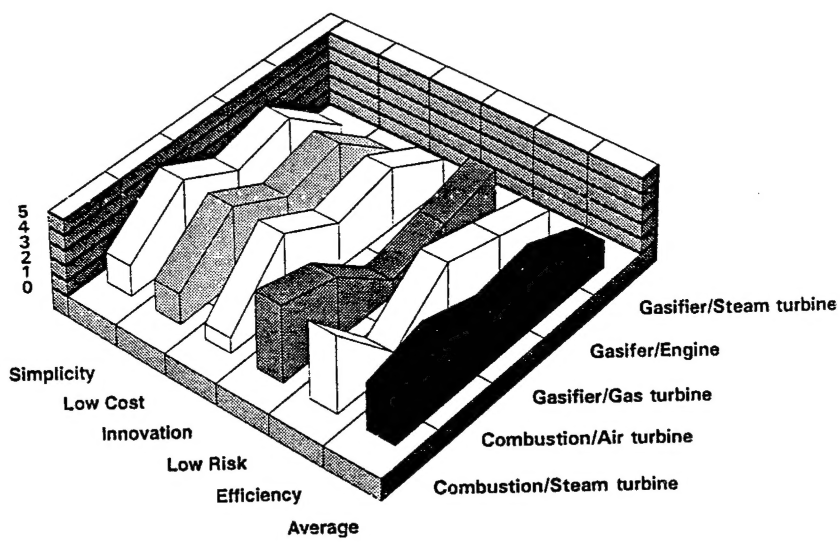

FIGURE 1. Preliminary technology comparison (Ranking 1 to 5, 5 = best)

All of the preferred options will produce electricity at relatively low efficiency, in the range of 9 to 18% of the energy in the fuel (compared with 30 to 35% for large utility power plants). Commercial operations at this scale will almost certainly incorporate cogeneration or other recovery of waste steam or hot gas energy. However, there are a few technical difficulties involved with waste heat recovery, and the demonstration must concentrate on the technical challenge of electrical power generation at small scale but low cost. The issues of waste heat and cogeneration will be addressed by simulation and incorporated in the overall system design for ultimate commercial operation. A waste heat recovery approach that has been proposed for the project is wood drying. Use of dry wood in the furnace or gasifier can improve conversion efficiency by up to 20%, when wood is dried from a normal harvested condition of 50% moisture to 25% moisture. Project analysis will investigate the lower cost of drying wood in storage piles. If waste heat is used (especially in winter) to expedite drying, then wet flue gases should be avoided. Instead, a very simple form of heat exchanger and a low volume auxiliary fan can send hot, dry air to the storage area, or engine exhaust may be used.

Two other factors are also critical: 1) vendor reliability, track record, and project personnel, and 2) the quoted cost of the installed prototype system (not the same as the estimated commercial cost of a standardized system). Final selection is expected in November 1994.

Technology selection, final design, fabrication, and on-site installation are planned for the first 2 project years. Shakedown, testing, and final operation status will be achieved in the third and final year. The project will be analyzed and documented, including equipment, procedures, operational performance, emissions and other environmental factors, and economics. The facility will remain on the site, operated by Base personnel, with connection into the local electrical grid.

This project is ideal for smaller companies. Smaller developers are dedicated to their biomass energy technologies and are typically willing to make substantial investment in the project. They usually apply creative engineering to balance simplicity of installation and operation, low installed costs, and improved efficiency of biomass-to-energy conversion.

Vendors and the prime contractor are currently completing equipment descriptions of:

- Fuel converter(s) (gasifier, combustor -- furnace area, furnace volume, gasifying zone, disengagement zone, grate, tuyeres, nozzles)

- Fuel handling (loaders, conveyors, hopper, furnace feed system; e.g. screw conveyors, truck unloading, ramps, grinder/chipper)
- Ash removal (dampers, dumpers, grates, duty cycle)
- Gas cleanup (cycle, filters, bags)
- Heat recovery (heat exchangers, fans)
- Engine/turbine(s) generator set
- Fans/pumps (air preheating, fan descriptions, dampers, motor controllers)
- Switch gear
- Sampling and other test equipment (thermocouples, infrared sensors, pressure gages and transducers, flowmeters/anemometers, weighing scales for fuel and ash, weighing hopper, gas analyzers, electrical meters -- voltage, current, watts)
- Data acquisition system
- Control panel, controllers, control room and office (potential for a remote control station)

Operations and testing are practically indistinguishable for the demonstration project. Testing will be concerned with recording data to define various aspects of the operation:

- time for installation
- major technical problems and solutions during installation and operation
- labor requirements and operating procedures
- major equipment costs and performance ratings
- instrumentation and test procedures
- fuel analysis; ash analysis including ash fusion temperature and alkali content; grab samples can be taken periodically for fuel analysis to ensure that the entire fuel mix is being characterized
- tar and particulate production and capture; gas concentrations of solid and condensed matter are important
- mass and energy balances for fuel handling/drying, fuel conversion, turbine, product gas, flue gas, water/steam, and waste heat recovery
- spot sampling of typical process temperatures, pressures, gas velocities, and residence times
- emissions analysis including CO_2, carbon monoxide, nitrogen oxides, tars, and particulate matter; engine exhaust is of particular interest due to its potential use in fuel drying
- electrical power production; efficiency and heat rate
- auxiliary power requirements
- fuel flexibility
- furnace heat release rate
- turbine set or engine efficiency
- efficiency contribution of fuel drying
- investment costs; on per kilowatt and per kilowatt-hour basis

- operating costs, especially contribution of fuel costs, fuel drying, and cleanup/disposal

The preliminary test plan calls for 10 short term tests of 8 to 24 hrs per test. Long term tests will increase to 50, 100, 250, 500, and 1000 hrs. The longest test requires at least 42 days or 6 weeks of 24-hrs/day operation.

Demonstration results will be compared with other available, small-scale technologies, including diesel fuel and gasoline-operated generators, and package boilers (wood, coal, oil, gas).

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